

Estimating and Projecting the Size and Impact of the HIV/AIDS Epidemic in Generalized Epidemics: The UNAIDS Reference Group Approach

by

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The UNAIDS Reference Group on Models, Estimates and Projections²

¹This paper reports the results of research and analysis undertaken by U.S. Census Bureau staff. It has undergone a more limited review than official U.S. Census Bureau publications. This report is released to inform interested parties of research and to encourage discussion. The views expressed in this paper are those of the author(s) and do not necessarily represent the view of the U.S. Census Bureau.

The use of data not generated by the U.S. Census Bureau precludes performing the same statistical reviews on those data which the U.S. Census Bureau does on its own data.

²The UNAIDS Reference Group; on Models, Estimates and Projections consists of a core group of members supplemented by invited experts for special topics. Those participating in this work include Marc. Artzrouni, Tim Brown, Griff Feeney, Geoffrey Garnett, Peter Ghys, Nicholas Grassly, Stefano Lazzari, David Schneider, Karen Stanecki, John Stover, Bernhard Schwartländer, Neff Walker, Peter Way, Ping Yan, Basia Zaba, and Hania Zlotnik. Many others provided data and participated in discussions about generalizing the available data to apply to the global estimates.

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Abstract

Every two years UNAIDS prepares estimates of the HIV/AIDS epidemic for every country in the world. In preparation for the 2001 round of estimates, the UNAIDS Reference Group on Models, Estimates and Projections developed a new modeling approach and updated many epidemiological assumptions. The new approach includes (1) a new model (Epidemic Projection Package) for estimating and projecting HIV prevalence from HIV surveillance data; (2) updated assumptions about rates of progression from infection to death for adults and children, the fertility impact of HIV, and the distribution of HIV infection by age and sex; (3) an updated version of the Spectrum software to integrate HIV and population projections with the latest demographic estimates from the UN Population Division and (4) a new methodology for estimating maternal, paternal and double AIDS orphans. This paper describes the methodology, assumptions and results from this work.

Introduction

The UNAIDS process for estimating the size of the HIV/AIDS epidemic for each country in the world involves estimating the trend of HIV prevalence from surveillance data and using a demographic and HIV projection model to estimate the number of people infected, the number of AIDS cases, the number of AIDS deaths, the number of perinatal HIV infections and the number of AIDS orphans. Estimates have been prepared previously for 1994, 1997 and 1999. [Schwartlander *et al*, 1999] In preparation for the 2001 round of estimates, UNAIDS received assistance from its Reference Group on Estimates, Models and Projections. The Reference Group has:

1. Developed a new model for estimating and projecting HIV prevalence from available surveillance data. This model, called the Epidemic Projection Package or EPP, replaces EpiModel used in previous estimates;
2. Recommended the use of the Spectrum software to make the demographic and HIV projections based on the prevalence estimate;
3. Reviewed the latest data and revised previous assumptions about the distribution of HIV infection by age and sex, the impact of HIV on fertility and the rate of progression from HIV infection to AIDS death; and
4. Developed new procedures for estimating paternal and double AIDS orphans.

Estimating HIV prevalence

Most countries with serious HIV epidemics have active surveillance systems that collect information on HIV prevalence among various population groups such as pregnant women, commercial sex workers, hospital patients, TB patients and patients receiving treatment for sexually transmitted diseases. For generalized epidemics (where prevalence is above one percent in pregnant women) the data from antenatal clinics are most representative of the general adult population. However, surveillance data come from various geographic settings at various times. In order to use all the available data to make the best possible estimate of HIV prevalence over time, the Reference Group developed a new model called EPP. This is a simple epidemiological model that divides the adult population into two major groups: those that are not at risk of HIV infection and those that are at risk. The susceptible population is further divided into those with HIV and those without HIV. Those with HIV can progress to AIDS and death. All groups can die of causes other than AIDS. The model calculates births in each year and ages them to age 15 when they enter the adult population.

The model is defined by three differential equations that determine the change through time in the size of the not at-risk population N , the at-risk, susceptible population S , and the infected population I .

$$N_t = N_{t-1} - \mu * N_{t-1} + (1-f_t) * R_t$$

$$S_t = S_{t-1} - \mu * S_{t-1} + f_t * R_t - r * I_{t-1} / P_{t-1} * S_{t-1}$$

$$I_t = I_{t-1} - \mu * I_{t-1} + r * I_{t-1} / P_{t-1} * S_{t-1} - A_t$$

$$P_t = N_t + S_t + I_t$$

$$f_t = \exp(\phi * (N_{t-1}/P_{t-1}) - (1 - f_0)) / \exp(\phi * (N_{t-1}/P_{t-1}) - (1 - f_0) + 1/f_0 + 1)$$

Where:

N = adult population not at risk

S = adult population at risk but not infected with HIV

I = population infected with HIV

P = total population

R = number of 15 year olds

A = number of AIDS deaths

μ = non-AIDS mortality rate

f = proportion of 15 year olds entering the at-risk population

r = the force of infection

The number of AIDS deaths is determined by progressing new infections to death according to a weibull pattern with a median time from infection to death of nine years.

The model is specified by four parameters:

f_0 = the fraction of the population at risk in the base year

t_0 = the first year in which HIV infection enters the population

r = the force of infection

ϕ = a parameter determining the degree to which AIDS deaths in the at-risk population are replaced by an increased fraction of new recruits entering the at-risk population.

The effect of the four parameters is shown in Figure 1. t_0 sets the start date of the epidemic, r governs the rate of increase during the explosive phase of the epidemic, f_0 determines the peak prevalence and ϕ determines the amount of decline after the peak that occurs because of AIDS deaths among those at risk.

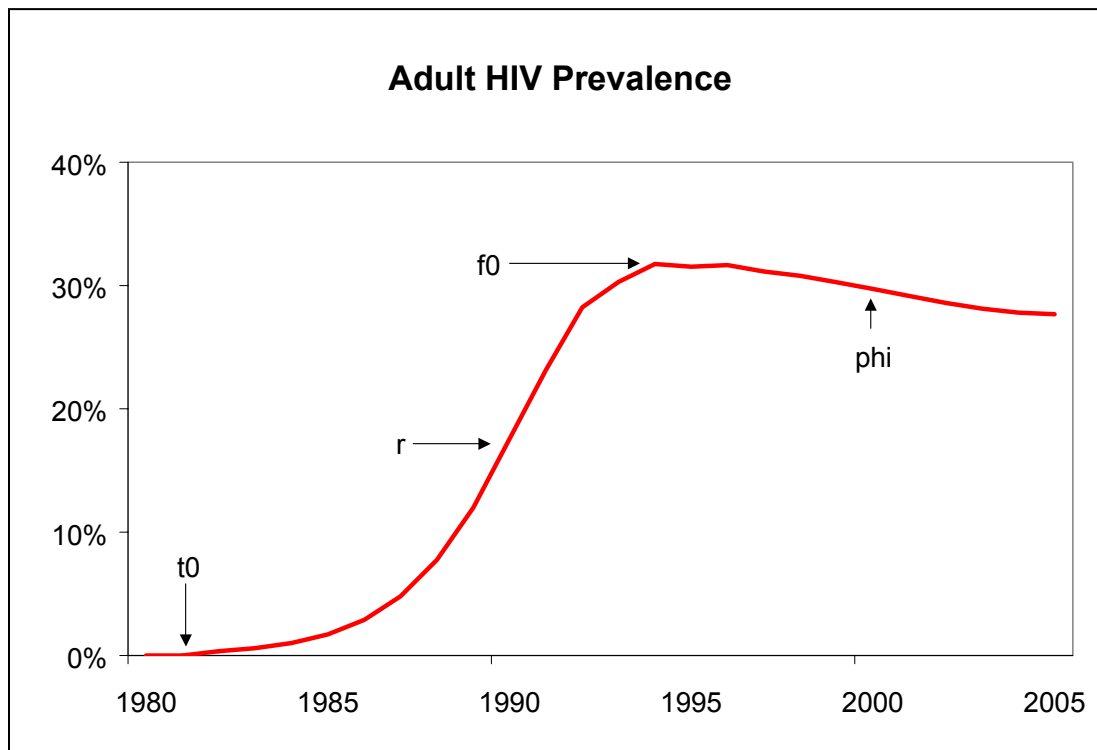
This model has been programmed into an interactive computer program by Tim Brown and Wiwat Peerapatanapokin of the East West Center. The program is used to estimate prevalence curves for every country with a generalized epidemic.

The model is applied to any geographic area data by finding the values of these four parameters that produce the best fit to the available surveillance data. For generalized epidemics the model is fit separately to the urban and the rural surveillance data. The resulting prevalence estimates are combined to yield an estimate of prevalence over time for the country as a whole. The model is available on the Internet¹³. Surveillance data are taken from the HIV/AIDS Surveillance Database of the US Bureau of the Census. [Census, 2001]

This model has been applied in countries with heterosexual epidemics, primarily in sub-Saharan Africa. Estimates of prevalence in countries with concentrated epidemics rely on estimates of prevalence by risk group (men who have sex with men, commercial sex workers, injecting drug users) and the size of each risk group.

³ To download the model and manual, go to www.tfgi.com, click on "Software", "EPP" and "EPP" again to see the download page.

Figure 1 The influence of the four parameters on the basic epidemic curve



Demographic and HIV projections

Adult HIV prevalence is the basis for estimating a number of demographic and epidemiological indicators, such as the number with HIV, new HIV infections, AIDS deaths, newborns with HIV and AIDS orphans. These calculations are made using Spectrum, a modeling system developed by the POLICY Project⁴. Spectrum includes a demographic projection package that projects the population by age and sex using assumptions about the base year population and estimated and projected fertility, life expectancy and migration. [Stover, 2000] For the UNAIDS projections the base year population, total fertility rate and non-AIDS life expectancy are taken from the 2000 round of estimates and projections from the United Nations Population Division [UN, 2000]

Spectrum incorporates the impact of AIDS into the demographic projection through the following steps:

⁴ The POLICY Project is a USAID-funded activity that works to improve the policy environment for reproductive health in developing countries. It is implemented by the Futures Group International in collaboration with Research Triangle Institute and the CEDPA.

1. The estimated HIV prevalence is used to determine the number of adults infected with HIV in a given year.
2. The incidence of HIV is calculated as the number of new infections required to achieve the specified prevalence.
3. New infections are distributed by age and sex according to exogenously specified patterns.
4. New infections are progressed to AIDS and to death according to exogenously specified patterns.
5. AIDS deaths are added to non-AIDS deaths to determine total age- and sex-specific mortality in each year.
6. The number of HIV-infected women is used to calculate the number of babies born with HIV infection.
7. Children are progressed to AIDS and death according to exogenously specified patterns.
8. AIDS orphans are calculated from AIDS deaths to adult men and women and the pattern of female and male fertility over time.

The key assumptions used in these projections are discussed in the following sections of this report.

The final output of Spectrum is a collection of demographic and HIV/AIDS indicators. Those reported by UNAIDS include:

- Number of adults living with HIV, by sex
- Number of children under 15 living with HIV
- Number of new HIV infections
- Number of new AIDS cases
- Number of AIDS deaths
- AIDS orphans

Patterns of HIV infection by sex

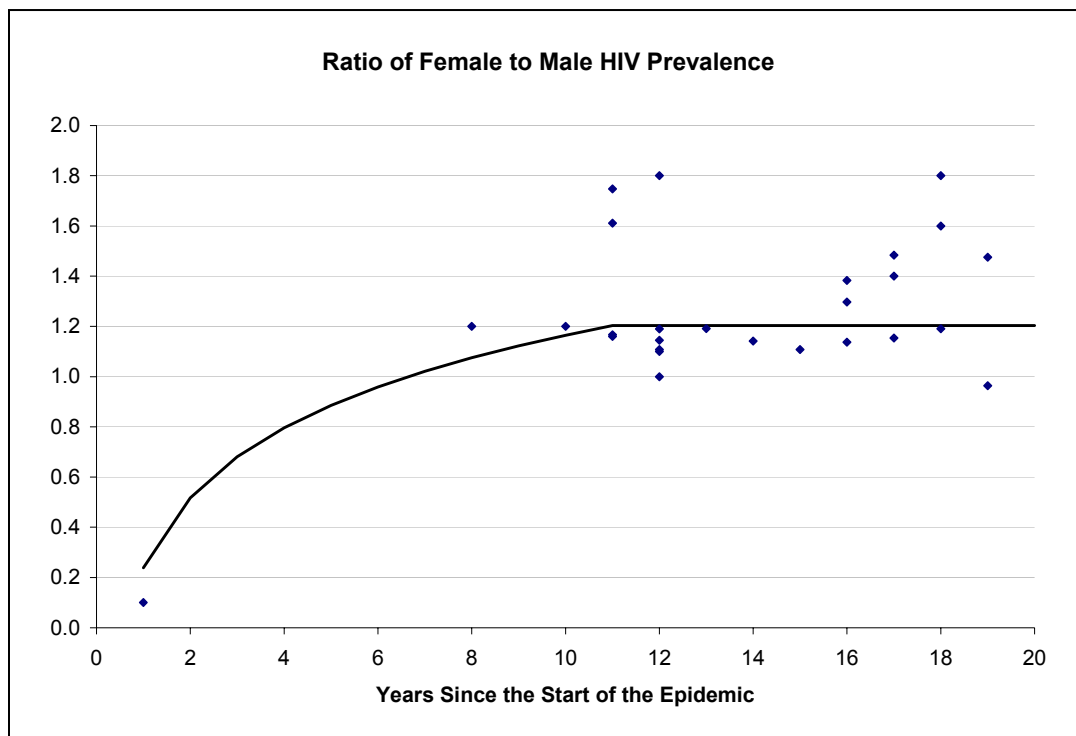
At the beginning of an HIV epidemic in heterosexual populations, many more men are infected than females. As the epidemic spreads to more and more people the ratio of female to male cases increases. In a mature heterosexual epidemic more females are infected than males. Population based surveys from a number of sites provide the data to describe the general trend. We have used data from 26 surveys from the following sites:

- Kisumu, Kenya, 1997 [Buve 2001]
- Addis Ababa, Ethiopia, two locations, 1994 [Fontanet, 1998]
- Mwanza, Tanzania, urban, village and roadside, 1990-91
- Masaka, Uganda, 1989-90, 1990-91, 1992-93, 1994-95, 1996-97
- Lusaka, Zambia, 1996 and 1999 [Fylkenses, 1997]

- Mposhi, Zambia. 1996 and 1999 [Fylkenses, 1997]
- Rwanda national population survey, 1986
- Uganda national population survey, 1988
- Rakai, Uganda, two trading centers and one village, 1990 [Wawer 1998]
- Fort Portal, Uganda, 1995
- Mutasa Estate and Mutasa Village, 1998
- Cotonou, Benin, 1997 [Buve 2001]
- Yaounde, Cameroon, 1997 [Buve 2001]
- Ndola, Zambia, 1997 [Buve 2001]

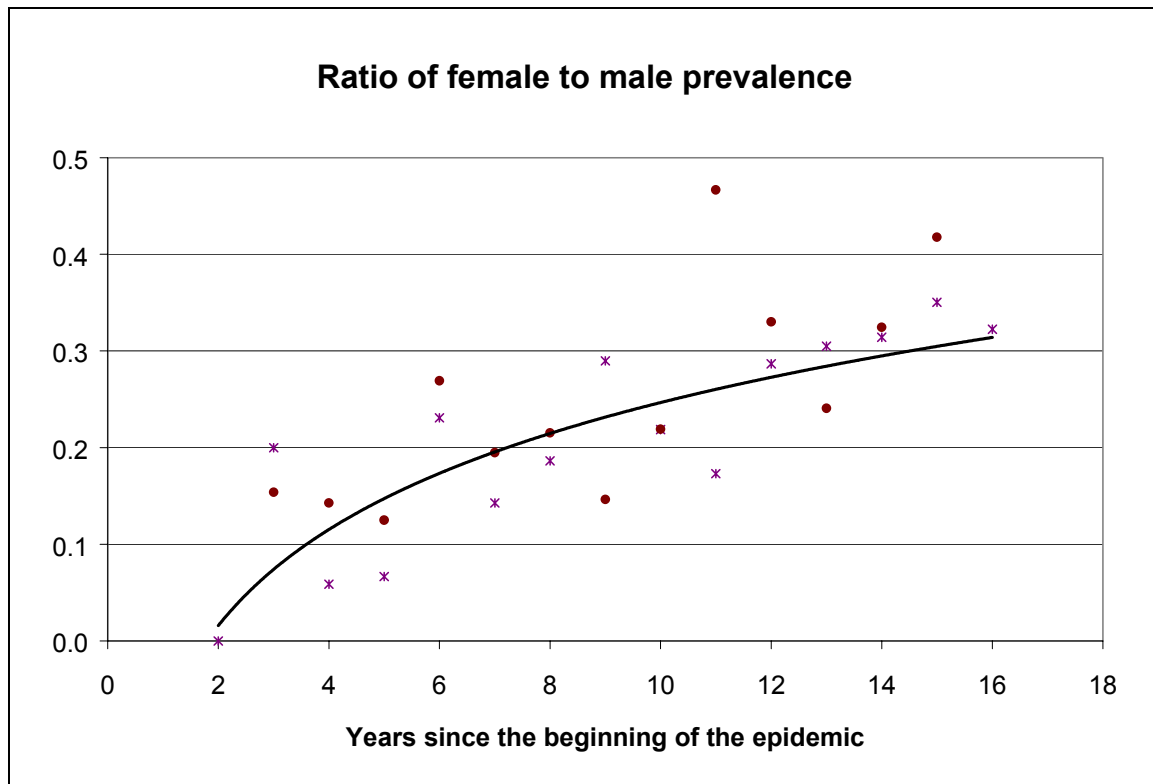
The pattern in the ratio of female to male HIV prevalence and the summary trend line used in the UNAIDS projections are shown in Figure 2.

Figure 2 The ratio of female to male prevalence over time in generalized epidemics



For epidemics that are driven largely by transmission among men who have sex with men or injecting drug users, the pattern is quite different, as male prevalence remains much larger than female prevalence. For these epidemics we use a pattern derived from reported AIDS cases in Central America, as shown in Figure 3.

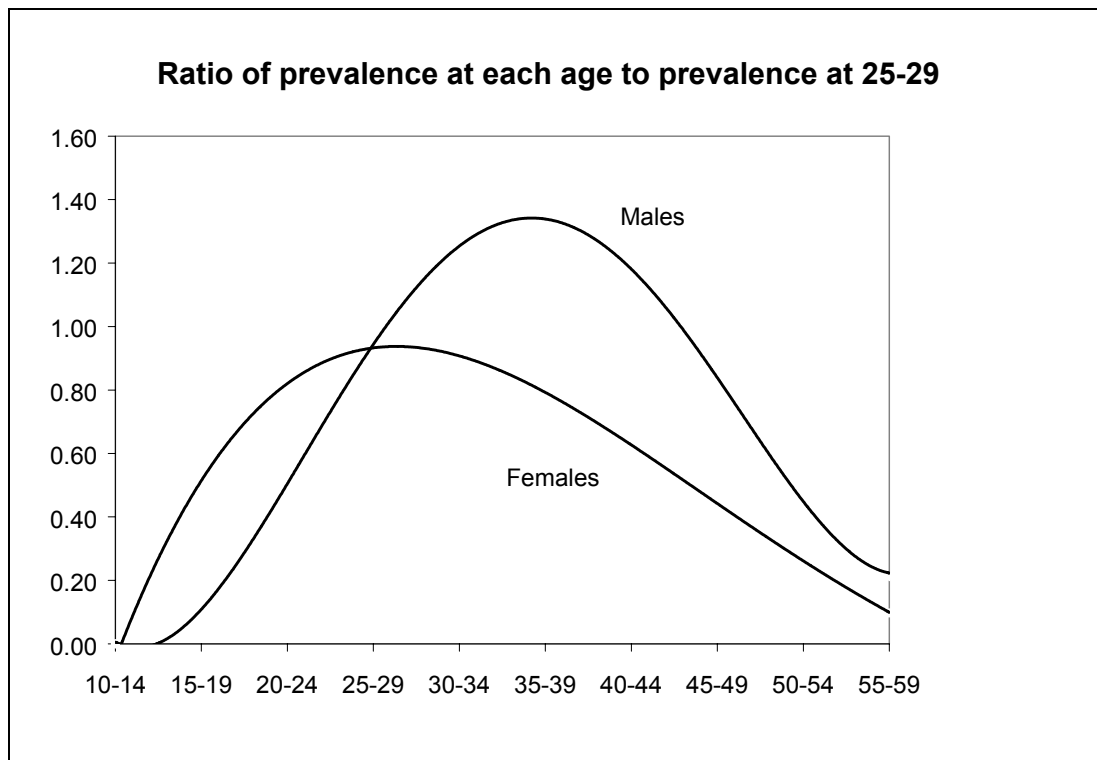
Figure 3 The ratio of female to male prevalence over time in homosexual or IDU epidemics



Age pattern of HIV infection

The age pattern of HIV infection in a heterosexual epidemic generally shows low prevalence in the early years of sexual activity increasing to a peak at about 25-29 years for females and somewhat later for males and then dropping to low levels after the age of 50. Data for these patterns are drawn from the same population-based surveys noted above. Figure 4 shows the male and female patterns.

Figure 4 The ratio of prevalence at any age to prevalence at 25-29 for males and females

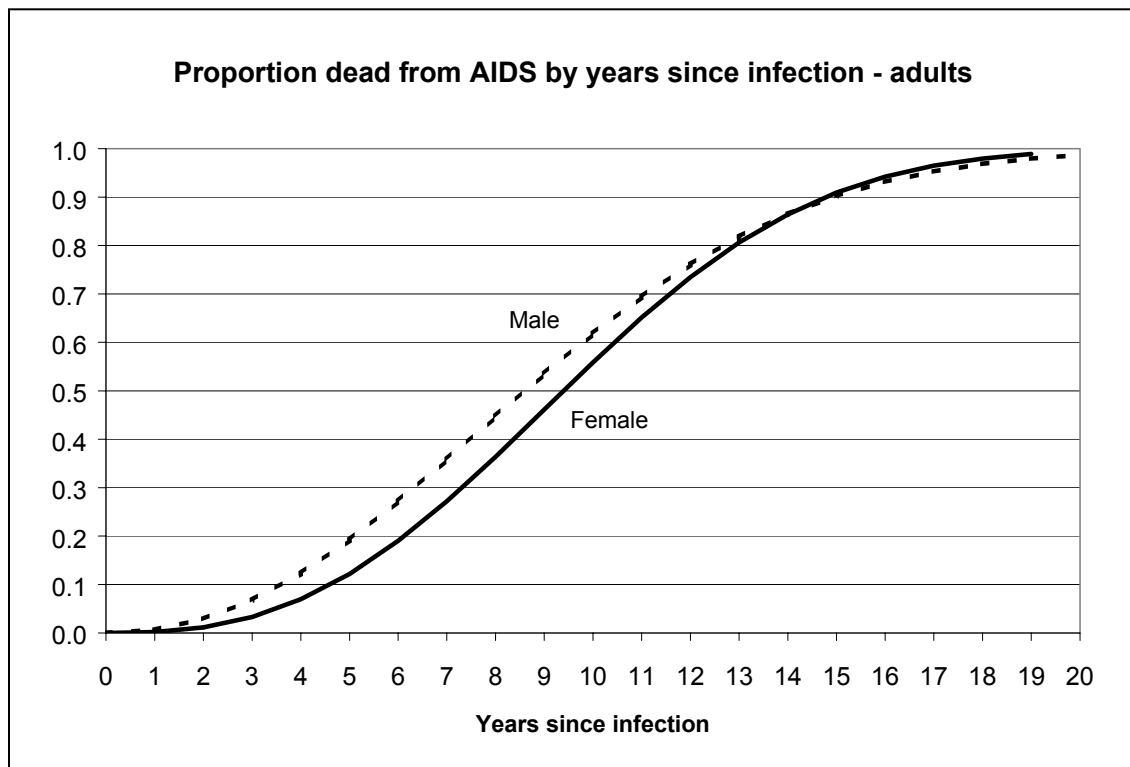


Progression from HIV infection to death

Before the availability of anti-retroviral therapy the median time from AIDS to death was about 10-12 years in the United States and Europe. These estimates were derived from cohort studies that followed a group of infected people over time. Few similar studies exist in the developing world. Studies from small cohorts in Uganda, Thailand and Haiti give an indication of the pattern of progression. [Bhrabant, 2001] These studies indicate a median survival time from infection to death of about 9 years. Females tend to live somewhat longer than males (9.4 years for females and 8.6 for males) mostly due to the fact that females tend to be infected at a younger age and younger people survive longer, on average, than older people. A weibull distribution is fit to the annual progression rates to develop the full pattern over time. The pattern is shown in Figure 5.

For children the pattern is quite different. Many children who are infected at birth die before reaching their first birthday. Others die by age five. A significant proportion survive beyond age five, but few seem to survive to age 15. Studies in eight developing countries (Thailand, Uganda, Cote d'Ivoire, Burkina Faso, DR Congo, Rwanda, Haiti and Brazil) provide information on the progression from infection to death. [Gray, 2001] The average pattern used for the UNAIDS projections was created by fitting a double weibull curve to capture the dynamics of some children who die quickly and others who survive beyond the first few years of life. That pattern is shown in Figure 6.

Figure 5 Progression from HIV infection to AIDS death for adults



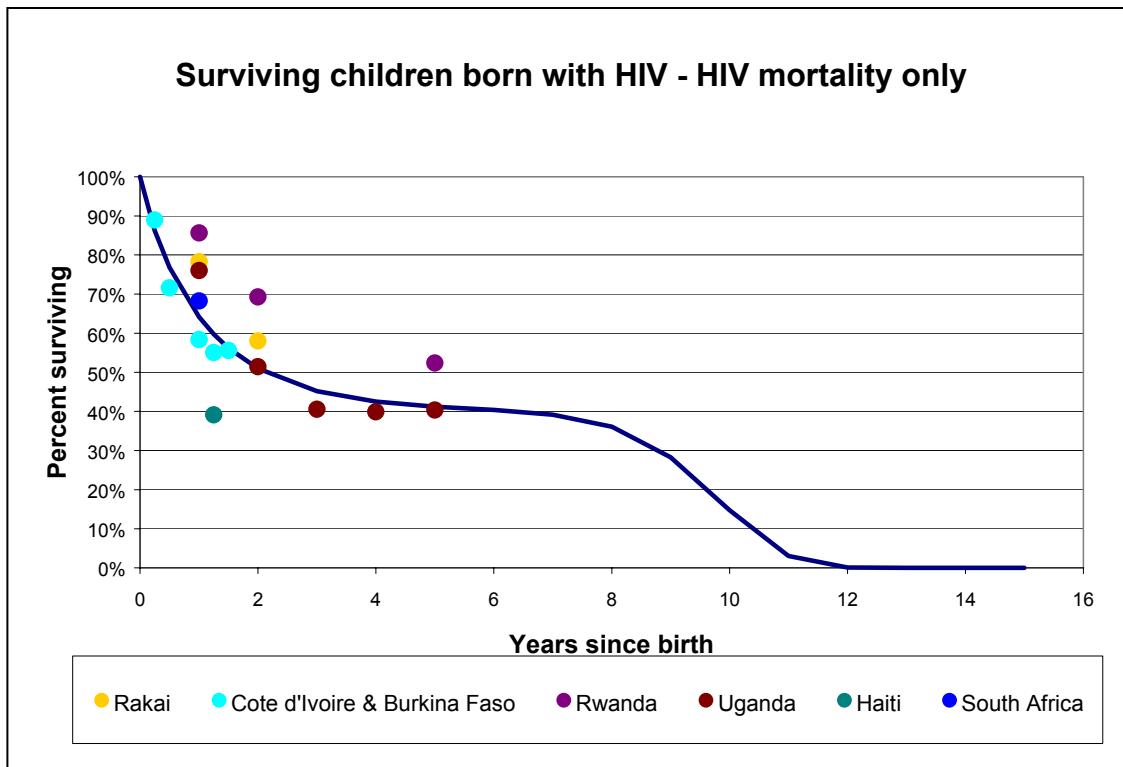


Figure 6 Progression from HIV infection to AIDS death for children

HIV infection and fertility

It is not clear how the total fertility rate might be affected by an HIV/AIDS epidemic. Some women who find that they are infected with HIV may want to have as many children as possible while they can, in order to leave descendants behind. Others may decide to stop childbearing upon learning that they are HIV positive in order to avoid leaving motherless children behind. Since the majority of people do not know if they are infected or not, knowledge of HIV infection is not likely to have a large effect on the desired fertility rate.

Age at marriage may also be affected and could, in turn, affect fertility rates. AIDS could lead to a lower age at marriage or first union if young women and their parents seek early marriage as a protection against the young woman having premarital sex with a number of different partners. This trend, in turn, could raise fertility rates if women are exposed longer to the possibility of pregnancy. Conversely, AIDS could lead to higher age at first intercourse as the dangers of unprotected sex become known. This trend would lead to lower fertility rates.

Gregson and colleagues have examined the question of the impact of HIV on fertility by examining potential changes in the proximate determinants of fertility (Gregson, 1994; Gregson et al., 1997). They found no clear evidence either way but concluded that the most likely result is that an HIV epidemic will slightly reduce fertility.

Two studies in Uganda found that HIV-infected women had lower fertility rates than HIV-negative women. One of these, in rural Rakai district (Gray et al., 1997), found that age-specific fertility rates for HIV-infected women were 50 percent less than those for women who were not infected. Another study among a rural population in Masaka (Carpenter et al., 1997), found that fertility rates were 20 to 30 percent lower among HIV-infected women. Since most women did not know their sero-status, the reduced fertility rates were most likely due to biological rather than behavioral factors. This finding suggests that fertility might be 20 to 50 percent lower among HIV-infected women. In societies with substantial use of contraception, there might be a reduction in contraceptive use that would partially compensate for this effect.

For the UNAIDS projections we have assumed that the fertility of HIV-positive women above the age of 20 is 20 percent less than for HIV-negative women of the same age. For women below the age of 20, HIV-infection indicates that a woman is sexually active, whereas not all women 15-19 are sexually active. Surveillance data from antenatal clinics compared with population-based surveys confirms that fertility is higher among young HIV-positive women. As a result, we assume that the fertility of HIV-positive women 15-19 is 50 percent higher than for HIV-negative women of the same age.

Orphans

A key demographic impact of the AIDS epidemic is the large number of AIDS orphans that result from AIDS deaths to adults. For the past several years UNAIDS has estimated and reported the number of maternal AIDS orphans. Maternal orphans are estimated from female AIDS deaths, the fertility experienced by the average women during the 15 years previous to the death and the AIDS and non-AIDS child mortality rates. Since paternal orphans have usually been ignored in these calculations, data on maternal orphans has actually referred to maternal and double orphans, since the status of the child's father is unknown.

Paternal orphans have not previously been calculated except as a ratio of maternal orphans. The Reference Group has developed a method for estimating paternal AIDS orphans that uses male mortality from AIDS and estimates of male fertility patterns. This new approach also takes into consideration the concordance of HIV infection between male and female partners. This allows separate estimation of the maternal orphans (mother dead from AIDS, father alive), paternal orphans (father dead from AIDS, mother alive) and double orphans. We have also defined dual AIDS orphans to include children with both parents dead and at least one parent dead from AIDS. The relationships are illustrated in Figure 7. [Timeus, 2001]

Figure 7 Definitions of AIDS orphans

		Mother			
Father			Dead		Alive
			AIDS	Other causes	
	Dead	AIDS	dual AIDS orphan	dual AIDS orphan	Paternal AIDS orphan
		Other causes	dual AIDS orphan	dual non-AIDS orphan	
	Alive		Maternal AIDS orphan		

Conclusions

These improved methods and assumptions have been used by UNAIDS to make the 2001 round of estimates and projections. The country-specific estimates will be released in July 2002. The global and regional estimates were released by UNAIDS on December 1, 2001. These estimates are shown in Table 1.

Table 1 Global and Regional Estimates Published by UNAIDS

Number of people living with HIV/AIDS	Total	40 million
	Adults	37 million
	Women	18 million
	Children < 15	2.7 million
People newly infected with HIV in 2001	Total	5 million
	Adults	4.3 million
	Women	1.8 million
	Children < 15	800 000
AIDS deaths in 2001	Total	3 million
	Adults	2.4 million
	Women	1.1 million
	Children < 15	580 000

Source: AIDS Epidemic Update December 2001, UNAIDS/WHO, 2001.

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